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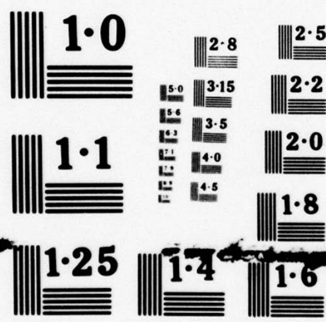
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HUMAN PERFORMANCE CENTER

DEPARTMENT OF PSYCHOLOGY

The University of Michigan, Ann Arbor

Interference Among Sources of Information in Complex Integrated Displays

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THE UNIVERSITY OF MICHIGAN
ARTES · SCIENTIA · VERITAS
1817

Technical Report No. 58
February 1977

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THE UNIVERSITY OF MICHIGAN

COLLEGE OF LITERATURE, SCIENCE AND THE ARTS

DEPARTMENT OF PSYCHOLOGY

INTERFERENCE AMONG SOURCES OF INFORMATION IN COMPLEX INTEGRATED DISPLAYS[1]

Patricia Somers and Robert G. Pachella

HUMAN PERFORMANCE CENTER--TECHNICAL REPORT NO. 58

February, 1977

This research was supported by the Office of Naval Research, Department of Defense, under Contract No. N00014-76-C-0648 with the Human Performance Center, Department of Psychology, University of Michigan.

ABSTRACT

The successful representation of complex information in a multidimensional display depends on the knowledge and exploitation of naturally occurring interdimensional relationships. Sets of dimensions vary in separability, the extent to which the perception of each dimension is independent of co-occurring dimensions. Nonseparability due to integrality among dimensions is distinguished from nonseparability due to masking and distraction. Integrality may result from two separate types of dimensional relationships, combination and interaction. Combination can be isolated from interaction using filtering tasks with no speed stress. A method for measuring combination by requiring filtering in a similarity judgment task is developed and a demonstration experiment is presented.

The successful representation of complex information in a multidimensional display depends on the knowledge and exploitation of naturally occurring interdimensional relationships. It is clear that a single response to a multidimensional stimulus can be made most efficiently when the perceptual response is also unitary. The nature of the perceptual response, however, varies with the choice of dimensions that define the stimulus. Some dimensions are perceived separately, some interact, and some combine into a single perceptual attribute. The present report examines the concept of interdimensional relationships in the perception of multidimensional stimuli. A distinction is drawn among various types of nonseparability, and a method for investigating one particular type of nonseparability is described.

An object can be verbally characterized, of course, by decomposing it into dimensions. A leaf is green, flat, smooth and of a particular shape. We are clearly able to discriminate the component parts of objects and to compare objects by referring to those parts. Whether perception proceeds by compounding these dimensions, however, is a problem that is both old and controversial. The question is complicated by the fact that the relationships among dimensions of an object are not of a single type.

Whether the percept of an object is built by adding simple dimensions, or whether it is directly based on higher-level structural aspects of the stimulus depends on how separable the dimensions actually are. Dimensions may interact so that the perception of their combination is not simply the addition of their separate effects, or dimensions may be entirely independent. Dimensions perceived by different senses, for example, may indeed be simply added to produce a percept. In addition, dimensions naturally co-occur with varying frequencies, so that two dimensions that correlate very highly may actually not be perceived separately at all. Nonseparability of dimensions in this sense might also be the result of receptor characteristics.

The task of discovering the relationship between the perception of an object and its dimensions thus entails specifying both the dependencies among the dimensions and their formation into a percept. The problem can be restated in the following way: The dimensions we have been discussing thus far are the experimenter's dimensions or the physicist's dimensions. They are the dimensions along which we have chosen to make our measurements of the physical world. They are not necessarily the psychological attributes of an object, the attributes used in perception, or the attributes with whose combination we should be concerned. Describing the interaction among the physically-specified dimensions of an object is another way of describing the psychological attribute that is actually perceived. With the assumption that a percept is a simple combination of psychological attributes, the problem of discovering the relationship between perception and dimensions becomes the problem of discovering the mapping of physically specified dimensions of an object onto its psychological attributes.

A distinction is drawn, then, between dimensions and attributes. Dimensions are aspects of the physical stimulus as opposed to the stimulus as encoded by the perceiver. They are usually continuous and not divisible into sub-dimensions. Attributes are the subjective aspects of the stimulus, and because they do not necessarily correspond directly to physical dimensions, they may be multidimensional. For example, one attribute of a leaf is its color. Color itself is divisible into three dimensions -- hue, value, and chroma. Whether hue, value, and chroma have psychological reality must be determined empirically.

The history of this problem dates back at least to the British associationists of the nineteenth century. According to James Mill's version of associationism, the perceptions of objects are compounded of synchronously associated ideas, ideas being copies of sensations. Thus, the perception of

a leaf is composed of the separate but simultaneous perceptions of color, shape, and texture. John Stuart Mill recognized the danger in this form of associationism carried to the extreme and abandoned the notion of mental compounding for that of mental chemistry. In this view, a complex idea or a percept is not simply the sum of an indefinite number of elements, but the parts combine in such a way that the whole is different from their simple sum. The idea is that elements generate rather than compose the whole; it is impossible to deduce the nature of the product from the characteristics of the elements which produced it. The theory diverges from previous associationism in an important way. J. S. Mill has recognized that elements, or attributes, may interact in their production of a percept, and that the product must be empirically observed to be characterized. (The emphasis on empiricism reappears in our translation of the problem into one of psychophysical mapping, for if a mapping is specific to a given stimulus, each stimulus must be individually observed.)

Gestalt psychology went one step further and denied the importance of association at all in the production of a percept (Kohler, 1929). The whole object is perceived directly. It is organized by the nervous system and has its own structure. The perception of the separate parts and the associations among them is only achieved afterwards. Indeed, an object can be divided into parts in any number of ways, and it is only after determing the nature of the whole that we can identify the parts appropriate for describing it. The notion is similar to the idea that the physical dimensions of a stimulus are specified somewhat arbitrarily with regard to perception and that the dimensions important for an analysis of the perceptual stimulus are the psychological ones. Once the psychological attributes of the stimulus are known, we can recognize which interactions and combinations of the physical dimensions give rise to the psychological attributes. The percept of an

object, though, cannot be approximated by an a priori description of its physical dimensions.

One approach to studying the relationships among attributes of objects has employed similarity scaling. In this approach, subjects provide information about perceptual experience by judging the similarity of pairs of objects. Shepard & Chipman (1970, p. 2) note:

> It is a fact of inadequately appreciated significance that, despite the practically unlimited range and diversity of possible internal representations, we can readily assess within ourselves the degree of functional relation between any two by a simple, direct judgment of subjective similarity. Moreover, we can do this even though (a) we have never before compared the two representations in question, and even though (b) we may be unable to communicate anything about the absolute nature of either of the two representations taken separately...One could even turn the matter around and argue that it is primitive, internal assessments of similarity of this sort...that mediate every response we make to any situation that is not exactly identical to one confronted before.

A nice demonstration of the point that similarity judgments are of basic importance in mediation of other responses may be found in the work of Isaac (1970), which showed that such judgments can be used to predict very accurately the behavior in a more complex "oddity" task.

In order to use similarity judgments to make inferences about perceptual attributes, however, a model is needed that relates the two. The earliest and simplest such model is Attneave's (1950) City-Block metric. According to this model, dissimilarity is a function of the summed perceptual differences on each of several attributes. Attneave applied this model to similarity judgments of parallelograms, varying in the physical dimensions of area and tilt, and to squares, varying in the physical dimensions of reflectance and area. In these applications, there was presumed to be a close correspondence between the physical dimensions and the perceptual attributes; for example, if A,B are two equal-sized small squares, differing in reflectance, and A',B' are two equal-sized large squares, with reflectances equal to those of A,B, then A and A'

will appear about equal in the psychological attribute of lightness, likewise, B and B', and the A,B similarity should be predicted to be equal to the A',B' similarity.

More generally, Attneave's model is representative of a class of models, in which it is assumed that there is a mapping of physical dimensions onto a vector of values of psychological attributes, and where the dissimilarity is assumed to depend, via some definite rule of combination, on the perceptual differences along each attribute. Some fairly broad subclasses of models of this sort were studies by Tversky & Krantz (1970). The key assumption in the entire class of models is that the psychological attributes determine the similarities according to some simple combination rule.

A rather different class of models begins with a geometric representation of the similarities, by means of a configuration of points in space, with small distances in the geometric model corresponding to high similarities between a pair of stimuli, and large distances corresponding to low similarity. In this model, a one-dimensional psychological attribute corresponds to an ordered series of curves or surfaces in the geometric space. An example of attributes specified by means of an ordered series of curves is the spatial configuration specified by the 1931 CIE Standard Color Observer. The spatial configuration does not necessarily yield the similarity of pairs of colors according to any simple rule involving a combination of Hue differences and Chroma differences. Such combination rules have been proposed (cf. Judd & Wyszecki, 1963, pp. 293-4) but there are other models in which similarity in color space is not modeled by any combination of attribute differences, but rather, by a metric defined independently of any coordinate system. For example, in MacAdam's (1944) metric the CIE diagram is crumpled into an irregular surface in 3-dimensional space, and after crumpling, the distance between any two points is given by the length of the shortest smooth curve connecting them and lying wholly on the surface

(no shortcuts through space). Such a definition of (Riemannian) distance does not depend on any coordinate system. Though the metric and the attributes are defined independently, there may be various empirical connections between them; for example, a contour of constant Chroma may be hypothesized to be an isosimilarity contour (constant metric distance) around the white point in color space.

In a similar vein, Chipman & Carey (1975) have emphasized the possibility that the spatial configuration is a model of primary importance, derivable from similarity judgments, and that even a 2-dimensional configuration may have many, many one-dimensional attributes which can be depicted within the configuration. They derived a 2-dimensional Euclidean configuration for similarities of narrow bands of white noise, varying in center frequency and power, and they showed that some attributes (loudness, volume, and density) might be represented by oblique linear axes in this configuration, but that pitch apparently could not be represented as simply.

These two approaches to modeling the connections between perceptual similarities and perceptual attributes converge in ambiguity when the Euclidean metric is used as a model of similarity. In the Euclidean model, the metric can be described as a simple function of differences along attributes (Pythagorean combination rule), so it can be employed as a model of the first sort; yet the coordinates can be rotated and translated without changing the combination rule, so that any two points in the configuration can be thought of as lying along a single one-dimensional attribute, or as a Pythagorean combination of differences along various pairs of orthogonal attributes. Thus, the Euclidean model can also be employed as one in which the configuration is a primary representation of similarities, and where there are many, possibly infinitely many different attributes that can be represented within the configuration, some as linear axes, others nonlinearly. Such perhaps was

Torgerson's original idea (1958, p. 254):

> For example, if a subject is required to rate a set of stimulus pairs with respect to their similarity, and the stimuli differ with respect to obvious and compelling dimensions, his ratings might very well behave as though they were a straight sum of the differences on the separate dimensions: that is, as though the subject were saying "These two stimuli differ this much with respect to brightness, plus this much with respect to size, plus this much with respect to shape."
>
> On the other hand, if separate dimensions are not obvious, the subject might be more likely to judge the over-all difference directly. In this event, we would expect the Euclidean model to show more promise.

This ambiguity of the status of the Euclidean model has led to some confusion. On the one hand, some users of popular multidimensional scaling programs have collected similarity data, fitted a 2- or 3-dimensional Euclidean configuration, and then have sought interpretation of a set of orthogonal axes in the configuration. The decision to interpret orthogonal axes has the effect of using the Euclidean model in mode 1, i.e., assuming that there is an underlying set of attributes whose difference generate overall dissimilarity according to a particular combination rule, the Euclidean rule. At the other extreme, several theorists (Garner, 1974a; Hyman & Well, 1967, 1968) have followed Torgerson's suggestion and used the Euclidean fit as a sign that the attributes in a particular stimulus domain are "unanalyzable" or "integral" and have drawn a contrast with "analyzable" or "separable" stimulus domains, in which the City-Block metric yields a better fit to the similarity data.

On the one hand, if similarity data are well described by a City-Block model, there is strong reason to suppose that the principal axes of the model correspond well to the salient perceptual attributes of the stimuli. On the other hand, if similarity data are better described by a Euclidean than by a City-Block model, there is not such a strong basis for supposing that the stimulus domain is unanalyzable. There are many reasons why the Euclidean model could fit better, even if the domain is highly analyzable (for example, a Pythagorean combination rule might simply be more descriptive than an additive

rule). In fact, the distinction between separability and integrality has been based on a number of converging criteria; the nature of the similarity configuration is only one of these. Integrality of attributes is based on the Euclidean model for similarities, sorting stimuli by similarity in free classification, loss in classification speed with orthogonal dimensions that must be filtered, and a gain in classification speed with redundant dimensions (Garner, 1974a).

There are also degrees and types of analyzability. We therefore require more than converging evidence -- we require a finer analysis than has heretofore appeared of the possible types and degrees of analyzability and their relation to performance in various kinds of tasks, including similarity judgments. Such an analysis is attempted below.

There are several practical problems which could benefit from a more detailed analysis of analyzability. In designing an integrated multidimensional display system, one must be able to interpret properly the results of psychophysical tests such as similarity scaling. It is also important to be able to predict the consequences of results arrived at using psychophysical methods for other sorts of performance that may be demanded of the display user. Such interpretations and predictions may be improved if the dichotomy of integrality vs. analyzability can be replaced by a more detailed classification.

Varieties of Nonseparability

The first dichotomy that can be drawn is between dimensions that are integrated into a single figure and those that are spatially separated. Attributes that are not presented in the same spatial location, for example the diameter of a circle and the inclination of an interior spoke, cannot be easily combined and mapped into a single response without a large cognitive contribution. In fact, Torgerson (1965) suggested that the amount of cognitive contribution to similarity judgments is an index of separability. Such dimensions are perceptually separable as well as physically separated. Torgerson (1958) would not term them dimensions at all, since they are not dimensions of a single attribute, but actually separate attributes of a figure. It is thus less relevant to an analysis of perceptual abilities to discuss the relative separability of such separated dimensions than of integrated dimensions. The separability of spatially distinct dimensions depends on such characteristics as their spatial proximity, while the separability of integrated stimuli depends to a larger degree on perceptual interactions among dimensions.

The remainder of this discussion will be concerned with integrated stimuli. The relationships among their component dimensions can be theoretically divided into several types.

<u>Interaction</u> Two dimensions of a stimulus interact if the perception or judgment of one dimension varies systematically with the level of the other dimension. The result is that discriminability of values on the first dimension cannot be assessed independently when the second dimension also varies. Identical pairs of values will differ in discriminability when accompanied by different levels of a second dimension.

Interactions vary in complexity. A simple interaction is exemplified by illusions such as this: tall rectangles appear to be larger in area than

shorter ones, where area is held constant. Thus, identical area values are perceived differently depending on the accompanying value of height. Height augments perceived area. The interaction is relatively simple because area values, not area intervals -- differences between pairs of area values -- are distorted.

On a more complex level, Krantz and Tversky (1975) found an augmentation between the area and shape of rectangles, such that equal shape intervals, defined physically, appeared larger as area increased. The converse was also true: area intervals appeared larger as shape increased. Krantz and Tversky suggested that if the change in appearance (increase or decrease) of an interval on one dimension as a function of an increase in the other is in the same direction for every interval of the first dimension, then two types of interaction are possible, augmentation and reduction. An example of reduction was found by Krantz (1972) in the realm of color, where chromaticness differences appeared smaller when a pair of colors was of high lightness than when it was of lower lightness.

<u>Combination</u> Two stimulus dimensions might interact in the sense just described but still be separable under certain conditions. If there is not a resource limitation on the perceiver's performance (e.g., pressure to respond quickly), he could choose to filter one interacting dimension from the other. To the extent that the perceiver cannot perform such filtering, the dimensions are said to be combined. Dimensions that do not interact can also be combined; interaction and combination are logically independent.

Different sets of physical dimensions perceptually combine to a greater or lesser degree. Combination is a continuum. Nevertheless, combination at the extreme is identical with integrality defined by the results of a free classification task. In this task, stimuli can be sorted into classes either along dimensional lines or based on overall similarity. When subjects ignore

the dimensional structure of a stimulus set and classify by similarity, the stimuli are said to be integral (Garner, 1974a). Essentially, the dimensions are combined into a single entity. Garner (1974a, p. 119) describes the combination in this way: "Psychologically, if dimensions are integral, they are not really perceived as dimensions at all. Dimensions exist for the experimenter . . . . [But they] do not reflect the immediate perceptual experience of the subject . . . ."

An example of combination can be found in similarity judgments of ellipses. If one were to compare the minor axes of two ellipses whose major axes are of different lengths, one could find the major axes impossible to ignore. In this case, the perceptual distortion of minor axes would not be systematic. The fact is, however, that the major and minor axes of an ellipse determine its eccentricity. The physically defined dimensions of length and width perceptually fuse in favor of the perception of the more salient attribute eccentricity.

The extent to which two physical dimensions combine is based on the psychophysical mapping of those dimensions onto psychological dimensions. If the physical and psychological dimensions are very slightly discrepant, physical dimensions will be easily filtered in a perceptual task. On the other hand, if the physical and psychological partitions of the stimulus space are at odds, the perceiver will act as if the two physical dimensions are one, which indeed they are, perceptually. Degrees of combination are obtained by intermediate dimensional discrepancies.

Integrality as broadly defined in the literature (Garner & Felfoldy, 1970; Garner, 1970,1974; Lochead, 1966) includes notions of both interaction and combination. Particularly in speeded tasks the two types of nonseparability yield similar results. Subjects behave as if they are using one psychological

dimension instead of the two physical dimensions. Nevertheless, any operational definition of integrality will have to distinguish between these two logically independent sources of behavior by developing tasks that differentially reveal them.

Additional characteristics of multidimensional stimuli can lead to behavior similar to that described above. Such characteristics are not related to dimensional integrality and again must be distinguished logically and operationally. They are described below.

Masking When one dimension of a multidimensional stimulus is so salient that it dominates the perception of a second dimension it can be said to mask it. Masking can be contrasted with interaction. When two dimensions interact, discriminability along one dimension depends on the level of the second; judgments of this dimension are systematically distorted. A masking dimension, however, actually prevents or interrupts the perception of the dimension that it masks.

An example of masking occurs in gustatory stimuli. A high proportion of salt in a salt-sucrose solution will prevent the perceiver from tasting the sweetness in the solution. Thus masking within a multidimensional stimulus is perfectly analogous to visual pattern masking, where the perception of the target, a letter for example, is disrupted by superimposing a pattern mask. The addition of a dominating dimension to a stimulus disrupts the perception of a less salient dimension, producing errors or slowing reaction time, but does not result in a systematic distortion of normal judgments.

Distraction Decrements in classifying levels of one dimension of a multidimensional stimulus may be obtained from the variation *per se* of a second, irrelevant, dimension. This phenomenon is known as distraction (Egeth & Pachella, 1969). When dimensions interact decrements in filtering performance in speeded tasks may result from the fact that discriminability drops at some levels of the

irrelevant dimension. Filtering decrements in speeded tasks can still be obtained, however, when dimensions do not interact and do not combine.

A performance decrement in speeded filtering given constant discriminability of the relevant dimension and perfect filtering in a nonspeeded task results from the fact that the perceiver must ignore a dimension that is varying irrelevantly. At least two possible explanations underlie the phenomenon. The first is based on the perceiver's limited capacity. Although filtering may be possible given unlimited time, forcing the perceiver to perform under speed stress reveals the resource limitations for this task. The second explanation is based on response competition: filtering is particularly poor when the perceiver must ignore a previously relevant dimension (Hodge, 1959). Neither of these sources of filtering decrements is due to perceptual interactions among dimensions. Thus, dimensions may be nonseparable as the result of performance characteristics of the perceiver, as well as characteristics of their psychophysical mapping.

<u>Logical Relations</u> Garner (1970, 1974a, p. 136) has suggested that "if in order for one dimension to exist the other must be specified, then the dimensions are integral." In order for a sound to have pitch, it must also have loudness, for example. The fallacy in this definition of integrality becomes evident by considering an outline rectangle. For the rectangle to have a size the lines that compose it must have thickness. The rectangle must also have a position in space. The dimensions of thickness and spatial position are necessary for the existence of the stimulus, but they are probably not integral with the rectangle's size, nor with each other. Stimuli are defined by constellations of dimensions, so that a given dimension may be logically necessary for the existence of a certain stimulus. A dimension is not, however, necessary for the existence of any other dimension considered in isolation. Thus, a given dimension may be required to have a non-zero value for a stimulus to exist,

but the relation of that dimension to the other dimensions of the stimulus is an independent issue.

Tasks

Classification Garner and his colleagues (Garner & Felfoldy, 1970; Gottwald & Garner, 1972, 1975; Pomerantz & Sager, 1975) have extensively investigated the perception of multidimensional stimuli using a speeded classification task in which subjects sort two dimensional stimuli into groups defined by one dimension, ignoring the other. In the control condition the irrelevant dimension is held constant. In the two experimental conditions the irrelevant dimension is either varied orthogonally with the relevant one, or is correlated with it. If the two dimensions are integral, according to Garner, subjects will be unable to filter in the orthogonal condition and there will be a loss in sorting speed compared to the control. In addition, integral dimensions will provide a gain in sorting speed when they are correlated.

Garner (1974a) has proposed that integrality be defined operationally by a converging pattern of results. These include the above pattern in speeded classification tasks, together with a Euclidean metric in multidimensional similarity scaling, and preferential classification according to similarity, as opposed to dimensions, in a free sorting task. According to this definition, value and chroma in a single color chip, and horizontal and vertical position of a dot were found to be integral. Value and chroma on two color chips, and the size of a circle and the angle of a diameter drawn through it were found to be separable (Garner & Felfoldy, 1970).

There are contradictions, however, with results found both in absolute judgment and discrete reaction time classification tasks. In the absolute judgment task, subjects identify the level of one dimension while a second dimension is held constant or varies. The task differs from speeded classification in that the subject is under no speed stress, and the number of levels

of each dimension is larger than the short-term memory span; since the analysis is based on confusions, subjects must make errors. Speeded classification tasks, on the other hand, typically use only two levels of each dimension. Egeth and Pachella (1969) found that subjects in an absolute judgment task could perfectly filter the vertical from the horizontal position of a dot. Garner and Felfoldy (1970), however, termed the dimensions integral, according to the speeded classification criteria.

The discrete reaction time classification task differs from speeded classification only in that speeded classification is performed with decks of cards, so that sorting time is obtained for an entire deck, instead of measuring reaction time for each trial. A more important difference between Garner's work with speeded classification and that of Morgan and Alluisi (1967), and Well (1971), who used discrete reaction time, is that the latter group of experiments vary either more than one irrelevant dimension or more than two levels of the irrelevant dimension concurrently. An increase in reaction time with increasing irrelevant information was evidence against subjects being able to filter dimensions such as size and color (Morgan & Alluisi, 1967), and position, orientation, and distance between dots (Well, 1971).

Discrepancies among results found using the three types of filtering tasks -- absolute judgment, speeded classification, and discrete reaction time classification -- can be explained by the fact that the three tasks require different amounts of perceptual processing capacity. There are two types of limitations on performance in these tasks (Norman & Bobrow, 1975). One is based on the amount of processing capacity required to filter. When available processing capacity falls below this level the task will be performed more poorly (Kahneman, 1973). The other limitation refers to the nature of the stimulus. If insufficient information is available, performance will be poor no matter how much processing capacity the subject has.

By definition, combination imposes a limit that is stimulus-based. Filtering is difficult because of the nature of two combined dimensions. Varying degrees of combination are not measured by the amount of processing resources used, but by the success of filtering when there is no resource limitation. Imposing time pressure on performance increases the amount of effort required to complete the task and will result in a performance decrement if the effort required exceeds that available. In an absolute judgment task the subject classified stimuli under conditions of minimal time pressure. Thus the nature of the stimulus, that is, the degree of combination between dimensions, will affect performance long before capacity limitations take effect. If the dimensions of a multidimensional stimulus are not combined, filtering performance should be no worse than performance when there is no irrelevant information to be ignored.

The speeded classification task, however, demands that the subject judge each stimulus as quickly as possible. Under these conditions, uncombined but interacting dimensions can produce filtering decrements similar to those that accompany combined dimensions in unspeeded tasks. While in an unspeeded task a subject might be able to overcome the effects of interacting dimensions and filter perfectly, a speeded task allows him less time to do so.

Interacting dimensions can increase filtering difficulty in two ways. The first was described by Egeth and Pachella (1969). When dimensions interact, discriminability along the relevant dimension is affected by the level of the irrelevant dimension. If discriminability along the relevant dimension in the control condition is greater than the average discriminability of the stimuli in the filtering condition, performance in the filtering condition will be poorer.

The second cause of poor performance is related to the effects of variable discriminability on responding. The stimuli in a speeded classification task

typically vary at two levels on each of two dimensions. When one dimension is held constant at a single level, the subject classified two levels of the relevant dimension into two categories. The effect of varying an interacting second dimension is to create, in essence, four instead of two levels on the dimension relevant to classification. While pairs of the levels are nominally and physically identical, perceptually they are different. The subject therefore classifies four levels into two categories, a task that Fitts and Biederman (1965) showed requires more time than a two onto two classification. This effect will produce a filtering decrement even when the level of discriminability of the control condition matches the average level of discriminability in the filtering condition.

The contrast between the speeded classification tasks in which no filtering decrements were found and the discrete reaction time tasks in which reaction time increased with the amount of irrelevant information can be explained by the fact that the latter tasks almost always involved more difficult or complex judgments due either to limitations imposed by stimulus discriminability or response demands.

Morgan and Alluisi (1967) found both errors and reaction time to increase with increasing amounts of irrelevant information when subjects classified stimuli by size and ignored color. Stimuli varying in size and brightness have been found to be separable in a speeded classification task, however (Gottwald & Garner, 1975). A major difference between the two experiments is in the discriminability along the relevant dimension. Morgan and Alluisi varied discriminability explicitly and found irrelevant color information to have a larger effect when stimuli were not very discriminable in size.

Well (1971) also found reaction time to increase with irrelevant dimensions for stimuli that had been termed separable in a speeded classification task (Imai & Garner, 1965). Well, however, presented six levels of the relevant

dimension, which subjects classified into two groups. Here, increased task difficulty could be the result of this six onto two classification instead of the usual two onto two stimulus to response mapping.

The lack of perfect filtering using stimuli that were perfectly filtered in the simple two-level classification tasks used by Gottwald and Garner (1975) and Imai and Garner (1965) indicates that factors other than dimensional relationships can generate the same pattern of results as does integrality. One of these factors, discriminability, is related to stimulus characteristics, but not to integrality. The others, speed stress and response complexity, are process factors.

Norman and Bobrow (1975) note that interprocess interference due to shared resources, as opposed to data limitations, will be revealed only when the processes are forced to operate under limited-resource conditions. Filtering tasks that impose speed stress essentially limit perceptual performance by taxing limited processing resources while the goal of the investigation is to determine the limitation imposed by the nature of the stimulus dimensions. Imperfect filtering in these tasks could be due to either interaction or integrality of dimensions, or both. When dimensions interact, a filtering task that does not add a process limitation is necessary to determine whether subjects can overcome the interaction, a sign of dimensional separability, or whether dimensions still remain unfilterable. Garner (1974b) explained the discrepancy between his finding that the vertical and horizontal position of a dot were integral and the finding of Egeth and Pachella (1969) that perfect filtering was possible for these dimensions in an absolute judgment task by stating that "optional selective attention" was operating. The difference in task demands between these two experiments indicates the point at which selective attention is optional. Integrality is a continuum. It is reasonable to expect that the influence of task demands and subjects' strategies will be most apparent when

stimulus dimensions are not at either extreme of the integrality spectrum.

Similarity Scaling It was previously noted that the Euclidean versus City Block metric criterion for integral dimensions in similarity scaling cannot distinguish the types of non-separability between dimensions. Multidimensional scaling in which subjects base their similarity judgments of pairs of stimuli on the overall appearance of the stimuli (that is, similarity scaling without filtering) can reveal the interactions that may exist between the dimensions of the stimuli. Krantz and Tversky (1975), for example, showed that an interaction between shape and area of rectangles resulted in a systematic distortion in the multidimensional scaling plot. Lines connecting stimuli of equal area in the plot were not parallel, but instead diverged as the level of shape increased.

Similarity scaling requiring judgments based on a single dimension, on the other hand, can reveal dimensional combination independently of dimensional interaction. The logic is similar to that of the filtering condition of an absolute judgment task. Subjects must filter one dimension from the other in making their similarity judgments. The lack of stress on speed or accuracy in this task maximizes the opportunity to demonstrate nonintegrality, regardless of dimensional interaction. The method has an advantage over the absolute judgment task in that is is specifically tied to similarity judgments -- the exact form of the perceptual distortion due to dimensional combination can be demonstrated by examining the psychological space of the stimuli as revealed by multidimensional scaling.

DEMONSTRATION EXPERIMENT

The remainder of this paper will be devoted to a detailed explanation of the similarity scaling-filtering method and the presentation of some results obtained by applying it. Like most filtering tasks, the filtering task in the context of similarity scaling consists of two conditions. In the control con-

dition, the irrelevant dimension is held constant. In the comparison condition, it varies. Subjects in both conditions base their similarity judgments of a pair of stimuli on a single dimension, the relevant dimension. To the extent that the relevant and irrelevant dimensions are combined, subjects will be unable to ignore the irrelevant dimension. In the comparison condition, where the irrelevant dimension varies, pairwise similarity ratings will be different from those of the control. It is expected that different dimensional pairs or stimulus sets occupy different points on the continuum of combination. The size of the difference between the control and comparison conditions indicates the degree of combination within a particular stimulus set.

A measure of combination, which we will call the distance ratio, can be obtained in the following manner. The values of the relevant dimension of the stimulus set are randomly divided in half. The values of the irrelevant dimension are also divided in half, but here the halves are not random. Instead, the halves are chosen so that all the stimuli in one half are more similar to each other than they are to the stimuli in the other half, with reference only to the irrelevant dimension.

There are actually two control conditions. In each, the irrelevant dimension is held constant; that is, the values of only one of the irrelevant-dimension halves is used, a different half for each condition. The comparison condition is created by pairing each of the relevant-dimension halves with one of the irrelevant-dimension halves. Thus, the stimuli of the comparison condition are identical to those of the control on the relevant dimension, but now half of the stimuli are of one type on the irrelevant dimension and half are of the other type.

Figure 1 illustrates the experimental design. The stimuli are schematic faces. The relevant dimension is outline shape and the irrelevant one is

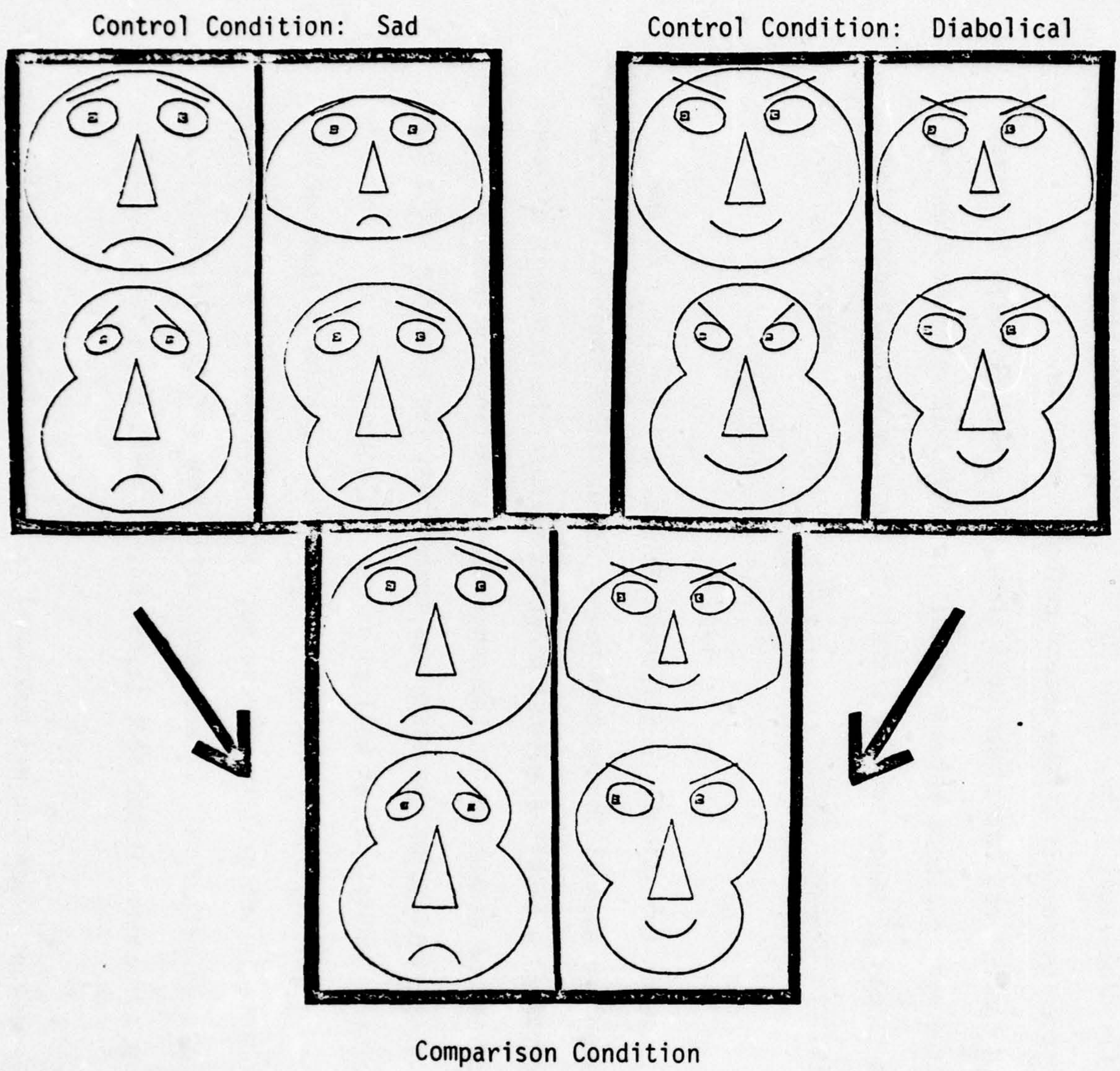

Figure 1. Experimental Design illustrated with four outline shapes.

emotional expression. The faces of the two control conditions and the comparison condition are identical in the values of outline shape represented. All of the faces in one control condition are sad and all the faces in the other control condition are diabolical. The comparison condition combines half of the sad faces with half of the diabolical faces, using the first half of the first control condition and the second half of the second control condition.

In both control and comparison conditions, the distance ratio is formed by comparing the mean distance between stimuli in different relevant-dimension halves with the mean distance between stimuli in the same relevant-dimension half. That is, the distance ratio = $\dfrac{\sum_i \sum_j d(a_i, b_j)/n^2}{\sum_i \sum_{j,\, i \neq j} d(a_i, a_j)/\frac{n(n-1)}{2}}$ where $d(a_i, b_j)$ is the distance between two stimuli in different halves, and $d(a_i, a_j)$ is the distance between two stimuli in the same half. The distance ratio in the control conditions serves as a baseline against which to measure the change in distance due to the pairing of dimensions in the comparison condition. Because it is a ratio of distances instead of the distances themselves, the distance ratio can be compared across conditions, as well as across subjects.

The use of the distance ratio was first applied to stimuli that seemed to be intermediate in integrality. These were schematic faces. Although they consistently scaled better with a Euclidean metric than a City Block metric, the elementary components of the face (eyes, nose, mouth, etc.) were spatially separated.

The irrelevant dimension was emotional expression, formed by specific combinations of eye slant and mouth curvature. Thus, this dimension corresponded to a variable of higher order than an elementary facial component. Since emotional expression was a characteristic of the face as a whole, it was expected that components of the face would be somewhat integral with expression.

The relevant dimension in this experiment was the shape of the outline of the face.

Method

The schematic faces were constructed by specifying values on nineteen continuous dimensions. They were drawn by a Calcomp Plotter under instructions from an Amdahl 470V/6 computer. In the present experiment all but six dimensions were held constant. These six were mouth length, mouth curvature, eye slant, eyebrow slant, height to width ratio of the face, and vertical position of a dimple in each side of the outline. Mouth length and curvature were combined to form four mouths, two frowning, and two smiling. Eye and eyebrow slant were combined to form four types of eyes, two slanting downward at the sides and two slanting upward at the sides. Smiling mouths and upward-slanting eyes were combined to form faces labelled diabolical, and frowning mouths and downward-slanting eyes were combined to form faces labelled sad. Because it is composed of a number of continuous dimensions and is not actually continuous itself, emotional expression as used here is properly termed an attribute, not a dimension, but since the distinction is not relevant to the use of the distance ratio method, the term dimension will be used for consistency.

The relevant dimension, outline shape, was composed of the orthogonal combination of four levels of height-to-width ratio and four levels of dimple position, for a total of sixteen stimuli. In the control conditions all sixteen faces were sad or all were diabolical. In the comparison condition, eight faces were sad and eight diabolical. The thirty-two faces are shown in Figures 2 and 3.

The ten subjects, obtained from the paid subject pool at the University of Michigan, participated in one experimental session each, consisting of one control and one comparison condition. Both control conditions were used: diabolical expression was the irrelevant attribute in one and sad expression was the irrelevant attribute in the other. The order of control and comparison conditions

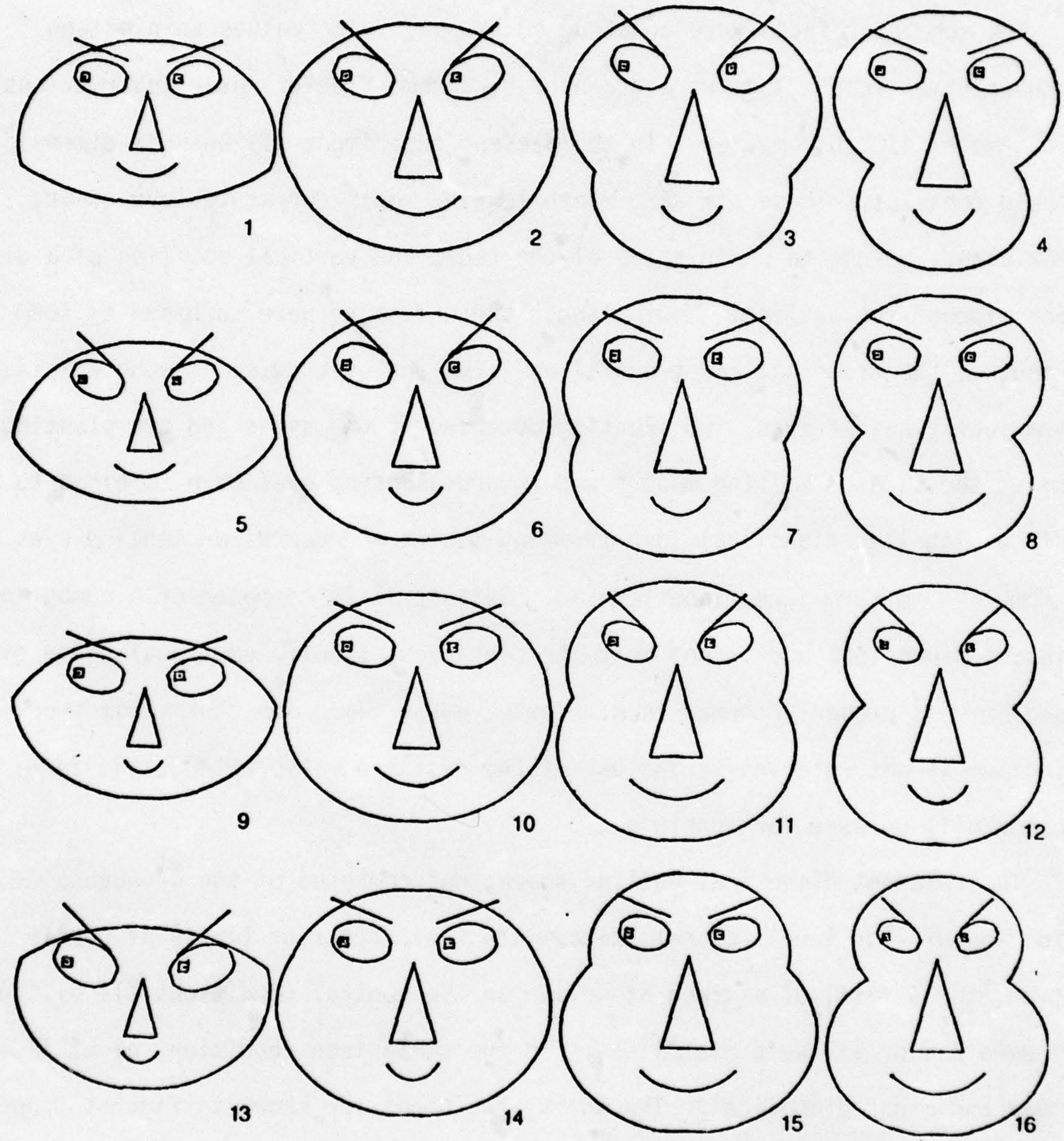

Figure 2. Faces varying in height-to-width ratio (rows) and dimple position (columns), with diabolical expressions.

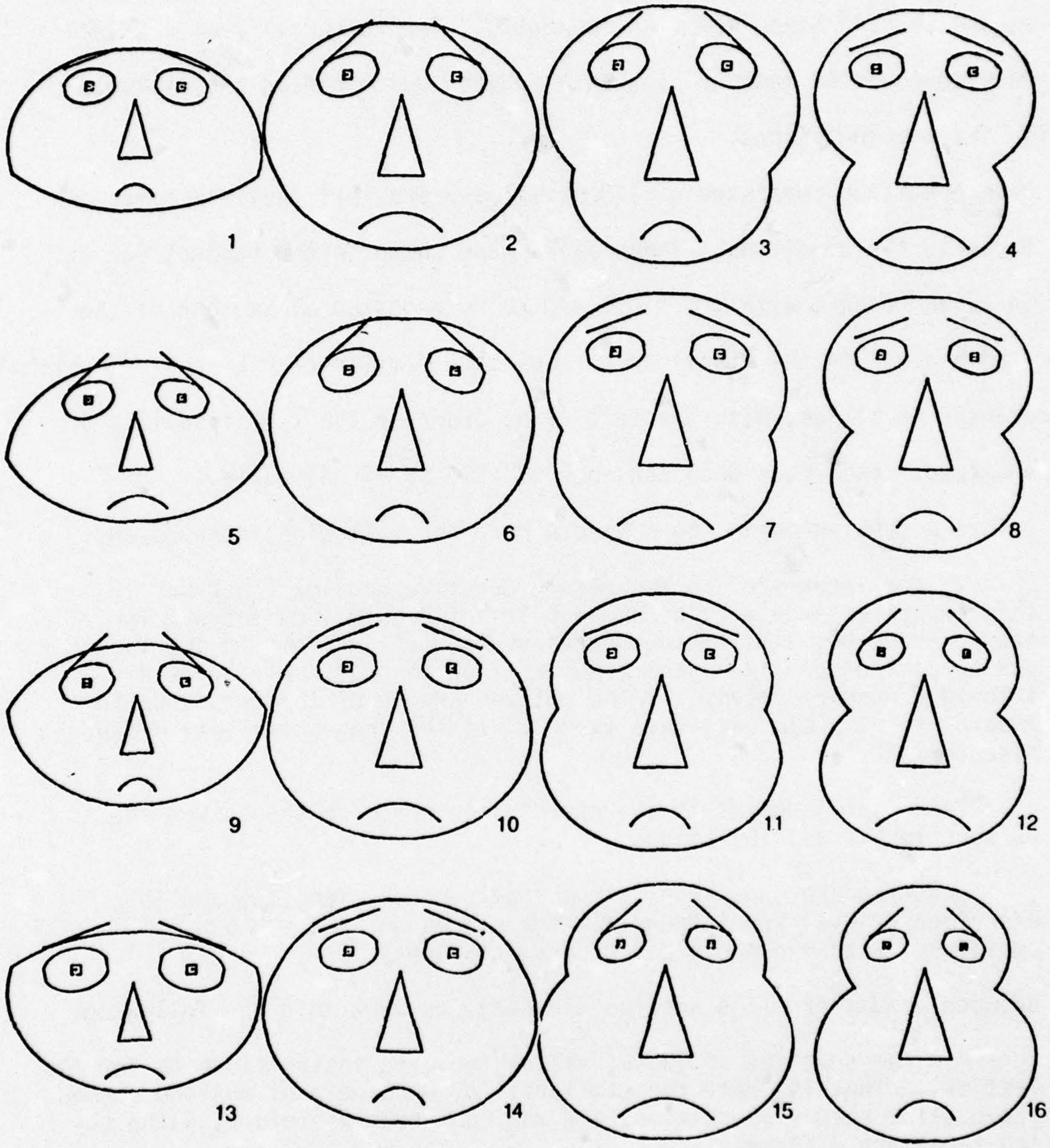

Figure 3. Faces varying in height-to-width ratio (rows) and dimple position (columns), with sad expressions.

was counterbalanced. Thus, there were four types of experimental sesssions: diabolical-mixed (two subjects), mixed-diabolical (three subjects), sad-mixed (three subjects), and mixed-sad (two subjects). The integrality of outline and expression could be measured for each subject by comparing the distance ratio for the two conditions.

Each condition consisted of 120 stimulus pairs, all possible pairs of the 16 faces in the condition. These pairs were shown to the subject one at a time in random order, with the first ten pairs repeated at the end of the sequence as a check on the stability of subjects' similarity ratings. The stimuli were presented on slides, with the left-right order of the two stimuli in a pair randomized. Each face occupied about 8° 20' of visual angle.

Before a session began the subjects read the following instructions.

> We are interested in how people perceive complex figures. In this experiment you will be shown pairs of drawings of faces. You are to judge how similar the shapes of the outlines of the two faces are to each other. Rate the similarity of the pair on a scale of 1 to 10 (integers only). If the outline shapes of the two faces in a pair are very similar, rate them 1. If the shapes are very different rate them 10.
>
> Mark your judgment in the appropriate space on the answer sheet. Be sure to use all 10 ratings.
>
> When you are done reading the instructions, look up, and the experimenter will run through all the slides so that you can get an idea of what the whole set of drawings looks like.

Between conditions in a session the subjects were told the following:

> For the next set of faces, follow the same instructions as for the last set. That is, rate the similarity of each pair of outline shapes. The outline shapes in this set are the same ones as before, although the faces are different.

Subjects were allowed as much time as they needed to make a judgment. The experimenter presented a new stimulus pair approximately every 20 seconds, but a subject could request more time if necessary. A session took from 90 minutes to two hours.

Results and Discussion

The similarity ratings made by each subject in each condition were subjected to a multidimensional scaling analysis using the Guttman-Lingoes program MINISSA (Guttman, 1968; Roskam & Lingoes, 1970). The ratings of the first ten stimulus pairs given at the end of the sequence were substituted for those made initially, on the assumption that these would be more consistent with the criteria used by the subject throughout the condition.

The distance ratio for each subject in each condition was calculated from the derived interstimulus distances given by MINISSA. Since interstimulus distance depends on the dimensionality of the space in which the stimuli are embedded, the proper number of dimensions for scaling each result was first determined.

In nonmetric multidimensional scaling, the configuration of stimulus points in the space is derived from strictly ordinal data, the rank order of similarity ratings of the stimulus pairs. Comparing the rank order of the similarity ratings with the rank order of the corresponding interstimulus distances in the scaled configuration gives a measure of the goodness-of-fit of the configuration to the data (Kruskal, 1964). This measure, called stress, can be used to determine the proper dimensionality of the stimulus space. If stress is high for a given configuration, an additional dimension is probably needed. A second criterion for selecting the proper dimensionality of the space is the interpretability of the dimensions. Adding dimensions will always lower stress, but these dimensions may not be meaningful.

In the present data, it was found that a maximum of two dimensions was interpretable for each subject. In addition, stress tended to decrease substantially from the one- to the two-dimensional solution, but adding a third dimension decreased stress only a small amount. On the basis of these

results, the two dimensional solution was chosen for each subject in each condition. It must be noted, however, that the distances in a solution of any dimensionality are monotonically related to the distances in a solution of another dimensionality, so that the pattern of results in terms of the distance ratios would remain similar.

The distance ratio for each subject in each condition was calculated according to the method described above. Table 1 gives the two-dimensional stress, the mean distance between stimuli within a half, the mean distance between stimuli in different halves, and the ratio of the last two quantities, the distance ratio.

The most apparent aspect of these results is that individual differences are large, both in stress and in distance ratio. Subjects 2 and 4, and Subject 8 to a lesser extent, show the type of distortion of the similarity space in the mixed condition expected if emotional expression influenced the similarity ratings; the distance ratio is substantially higher in the mixed condition than the control. Figures 4 and 5 demonstrate the basis of the distance ratio increase. Figure 4 is the two dimensional configuration of stimuli in the control condition for subject 2. The numbers representing the faces correspond to the numbers in Figure 2. There are four clusters of points corresponding to the four levels of height-to-width ratio. Dimple location apparently played little role in the perception of these faces. The stimuli numbered 1, 2, 4, 6, 8, 12, 14, and 15 composed one half and the remaining stimuli the other half. Since the halves were chosen randomly, and faces in both halves had a diabolical expression, the distances between stimuli within a half should be no different from the distances between stimuli in different halves, on the average. The configuration of the mixed condition, however, shown in Figure 5, indicates a large effect of the division between stimuli. Here faces 1, 2, 4, 6, 8, 12, 14, and 15 were diabolical

Table 1

Stress and distance ratios for comparison

vs. control conditions, subjects 1-10.

Subject	Condition	Stress in two dim.	Mean Distance between halves	Mean Distance within half	Distance Ratio
1	Ctrl-Diab.	.09	1.05	1.08	.97
	Comp.	.09	1.18	1.16	1.02
2	Ctrl-Diab.	.15	1.10	1.20	.92
	Comp.	.13	1.27	.60	2.12
3	Ctrl-Diab.	.07	.98	1.06	.92
	Comp.	.08	.97	1.01	.96
4	Ctrl-Diab.	.10	.93	.96	.97
	Comp.	.14	1.38	.64	2.16
5	Ctrl-Diab.	.09	1.14	1.15	.99
	Comp.	.08	1.02	1.03	.99
6	Ctrl-Sad	.09	1.00	1.08	.93
	Comp.	.002	1.32	1.36	.97
7	Ctrl-Sad	.06	1.15	1.24	.93
	Comp.	.02	1.14	1.15	.99
8	Ctrl-Sad	.16	.98	1.19	.82
	Comp.	.14	1.18	1.05	1.12
9	Ctrl-Sad	.04	.98	1.05	.93
	Comp.	.09	1.00	1.14	.89
10	Ctrl-Sad	.09	1.08	1.18	.92
	Comp.	.14	1.08	1.12	.96

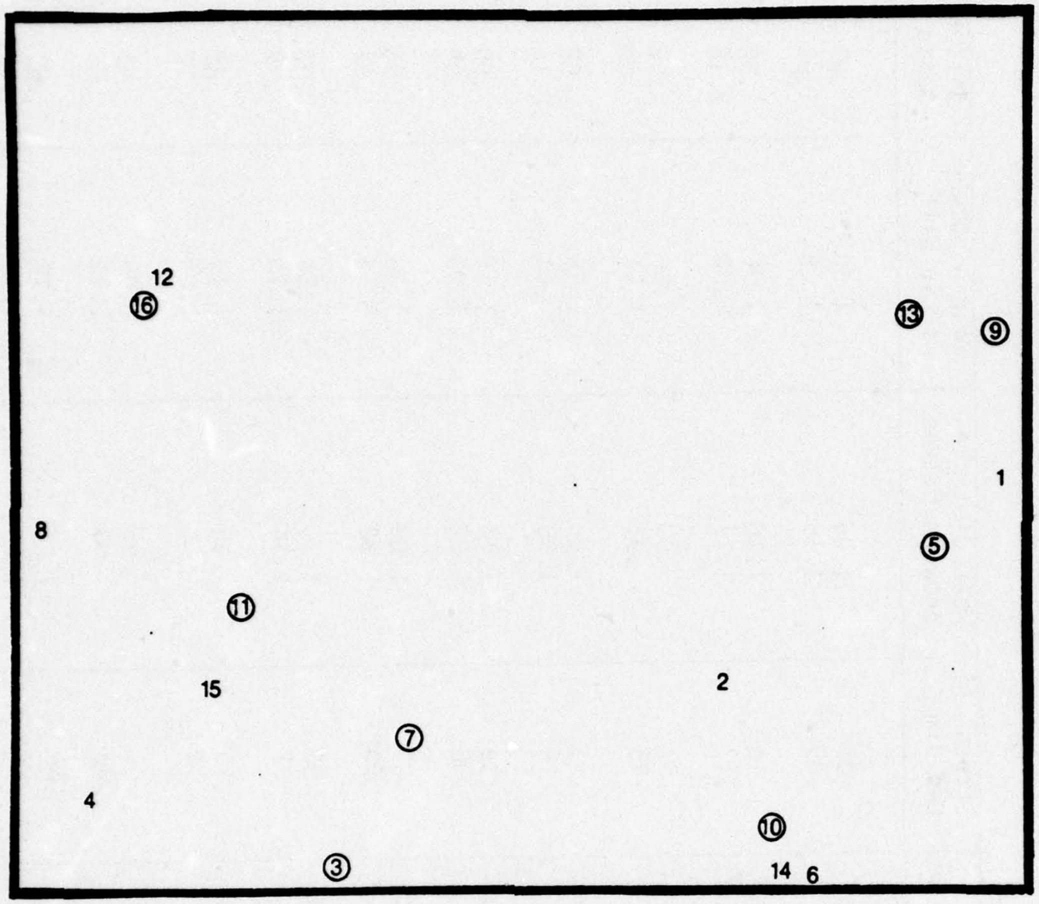

Figure 4. Multidimensional scaling plot of faces in the diabolical control condition for Subject 2. Numbers correspond to numbered faces in Figure 1. Circled numbers are in the same random half.

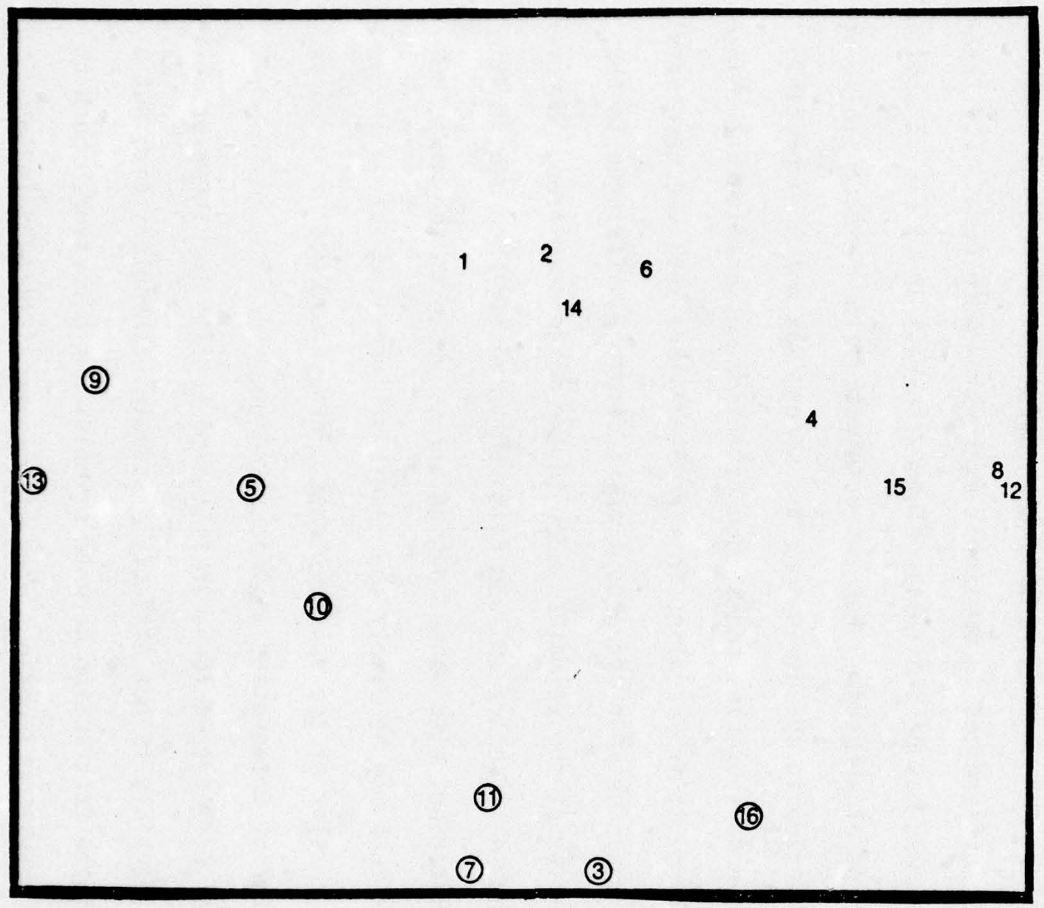

Figure 5. Multidimensional scaling plot of faces in the comparison condition for Subject 2. Circled numbers are sad faces; noncircled numbers are diabolical faces.

and the remaining faces sad. There are two dimensions to the configuration. One consists of the outline clusters as before. The other is clearly based on emotional expression. The mixed condition configurations for subjects 1, 3, 5, 6, 7, 9, and 10, in contrast, were quite similar to the control. These resembled the configuration shown in Figure 4.

The stress values for those subjects whose judgments of outline shape were influenced by differences in emotional expression were completely separable. The contrast in stress may be indicative of the contrast in filtering ability between these groups of subjects. For subjects who filtered successfully the stimuli could be scaled in one dimension; the second was not interpretable. For the other group of subjects, the second dimension was meaningful. Since lower stress will result from scaling in more dimensions than are necessary, the stress differences between the groups may indicate a difference in the proper dimensionality of the stimulus space in the mixed condition. However, it should be noted that subject 10, who filtered perfectly according to the distance ratio criterion, also showed a high stress value in the mixed condition. Since this may be simply the result of increased noise, a nonsystematic distortion of the space, stress alone should not be taken as a serious indicator of integrality in this paradigm.

The individual differences found in filtering ability for these stimuli indicate that integrality is not strictly a stimulus characteristic, but a characteristic of the interaction between stimulus and perceiver. Such an interaction is probably most obvious when stimuli are intermediate in integrality. The fact that some subjects were able to successfully ignore the irrelevant dimension indicates that outline shape and emotional expression are not at the extreme of integrality. The fact that some subjects did not filter emotional expression, at least given the present instructions, indicates that the dimensions are also not at the extreme of separability.

All of the nonfiltering subjects indicated that they felt that emotional expression influenced their judgments. Subject 8, for example, said that "if inner features (that is, emotional expressions) were very similar I tended to think (outline) shapes were more similar." The individual differences in the distance ratio demonstrate, then, that the present method is sensitive to influences on similarity judgments by an irrelevant dimension.

GENERAL DISCUSSION

The method described here has several advantages as an indicator of integrality. Because the method is tied to multidimensional scaling, the effect of a given dimension on the perception of similarity along a second dimension can be graphically demonstrated. While reaction time measures indicate only a gain or a loss in the time to make a judgment, an examination of the change in interstimulus distances, represented by the distance ratio, indicates the basis of that gain or loss.

If subjects can ignore the irrelevant dimension in the comparison condition, the distance ratio for this condition should equal that of the control. Theoretically, these should both be equal to 1.0. Since the relevant dimension values were divided in half randomly there should be no difference between interstimulus distances within a half and between halves. Since the number of stimuli is small, actual distance ratio values may deviate from 1.0, hence the use of the control condition as a baseline. If the irrelevant dimension contributes to subjects' similarity judgments, the distance ratio will be greater in the comparison condition than in the control.

A loss in classification speed in a filtering task is at least partially due to the fact that four stimuli instead of two stimuli map onto two responses. This can occur when a dimensional interaction produces four levels of discriminability on the relevant dimension, as described above. It can also occur

when dimensions combine, as pointed out by Garner (1974a). When two physical dimensions on which there are two levels of variation combine to create a single psychological dimension, the result is four stimuli that vary on one dimension. Again, there is a four to two, stimulus to response mapping.

The functional transformation of two stimuli in the control condition to four stimuli in the filtering condition is graphically demonstrated in Figures 4 and 5. To illustrate, consider stimuli 10, 14, 11, and 15. Stimuli 10 and 14 are at one level on the relevant dimension and 11 and 15 are at another. In the control condition, the irrelevant dimension is held constant. Figure 4 demonstrates that 10 is perceived to be more similar to 14, with which it shares a level on the relevant dimension, than it is to 11. The distance ratio of .92 confirms the lack of the influence of the irrelevant dimension on interstimulus distances. In the filtering condition, however, the irrelevant dimension is varied. Now stimuli 10, 11, 14, and 15 represent the orthogonal combination of the relevant and irrelevant dimensions. Figure 5 shows that the relative psychological distances have also changed; now 10 is more similar to 11, which matches it on the irrelevant dimension, than it is to 14. The distance ratio of 2.12 indicates that the irrelevant dimension now plays a role in determining the overall dissimilarity between the two stimuli. In the control condition, stimuli 10 and 14, and stimuli 11 and 15 were essentially the same stimuli. In the filtering oondition, they are four different stimuli.

A gain in classification speed typically occurs when two combined dimensions are correlated. The explanation is straightforward: the distance between two stimuli that differ on two dimensions is greater than the distance between stimuli that differ on one dimension (Garner, 1974a). A comparison of Figures 4 and 5 and their corresponding distance ratios demonstrates this fact. The distance between stimuli that differ on one dimension in the control condition and two dimensions in the comparison condition increases relative to a pair

that varies on only one dimension in both conditions. For example, the distance between stimuli 5 and 2 is less than the distance between stimuli 5 and 10 in the control condition, when both pairs differ only on one dimension. It is relatively greater when the irrelevant dimension is added.

It should be noted that throughout the discussion, the distances referred to are relative. A pair of stimuli can only become more or less dissimilar than another pair in the same multidimensional scaling plot. Because nonmetric multidimensional scaling is based on ordinal data, the distance scales in two different plots are not directly comparable. The numbers measuring interstimulus distances in a plot apply only to the scale of that plot. In effect, distance is measured by context. Two equivalent statements are that the distance between A and B has increased relative to the distance between A and C and that the distance between A and C has decreased relative to that between A and B.

The distance ratio measure mirrors this relativity perfectly. The effect of varying the irrelevant dimension in the comparison condition might be to decrease the psychological distance between stimuli sharing a value on this dimension. It might also be to increase the psychological distance between stimuli with different values on the irrelevant dimension. In terms of our experiment, the two possible changes in distances are these: outline shapes of two sad faces may seem more similar to each other when there are also diabolical faces in the stimulus set, or outline shapes of faces with two different emotional expressions may seem more different. In the context of nonmetric multidimensional scaling the two events are identical. The distance ratio measures the ratio of the average distance between stimuli with different values on the irrelevant dimension to the average distance between stimuli with the same value on the irrelevant dimension. It thus combines these two psychologically different but actually indistinguishable changes

in interstimulus similarity into a single measure.

The similarity space of a set of stimuli suggested by a multidimensional scaling analysis is firmly tied to subjects' similarity judgments, but the interpretation of the dimensions of the space is largely a matter of intuition. One common use of multidimensional scaling in the investigation of perception is to discover the psychological dimensions underlying the perception of a stimulus. Using the present method, we can find psychological dimensions by determining how a set of physical dimensions combine, not by trying to interpret the dimensions of the scaling solution per se. Thus certain pitfalls of multidimensional scaling are avoided, while its analysis of ordered similarity ratings is exploited. In fact, since the use of the distance ratio measure is independent of the interpretation of dimensions, it might also be computed by comparing the rank order of similarity ratings for identical pairs in the control and comparison conditions directly, thus avoiding the necessity of determining the dimensionality of the space.

Torgerson (1965) argued that similarity judgments are qualitatively different for stimuli that vary on several dimensions within an attribute, for example, color, than for stimuli that vary on several multidimensional attributes, for example, faces. In the latter case, groups of dimensions of the stimulus combine to form different attributes. Eye tilt and mouth curvature combine to form the attribute of emotional expression, for example, and height-to-width ratio and dimple location combine to form the attribute of head shape. Torgerson argues that similarity judgments that consider only dimensions within an attribute are perceptual and have properties of distance in space. Similarity judgments that take into account more than one attribute are more cognitive and not inherently spatial. Thus, the suitability of multidimensional scaling for multiattribute stimuli is questionable, when the interpretation of dimensions in space is the goal of scaling. While a dimension is continuous,

an attribute may only have nominal values that do not relate to one another in a clear way. It cannot be specified, for example, where the emotional expressions sadness and diabolicalness fall on a scale of expressions.

If one avoids assigning interpretations to dimensions of the space where it is not appropriate to do so, however, use can be made of the clusters into which multiattribute stimuli fall. Because the interpretation of dimensions is not a goal in the method described here, multiattribute as well as multidimensional stimuli can be investigated. This is done by focusing on relative interstimulus distances using the method of the distance ratio. The advantage is a major one, since the dimensions of many complex stimuli are not aspects of a single attribute, but may be nonseparable nonetheless.

The use of filtering instructions in similarity scaling has allowed the development of a continuous measure of dimensional combination, tied to a meaningful aspect of multidimensional stimulus perception. If combination is the extent to which physical dimensions mismatch psychological dimensions, the degree of combination in any stimulus set must be determined separately and empirically. The distance ratio measure provides one method with which to make this determination. While this method is an indicator of dimensional combination, as opposed to interaction, a complete picture of dimensional interrelationships can be obtained by combining the method with the use of multidimensional scaling without filtering. Repeating the set of similarity judgments with attention to both dimensions will indicate how the dimensions interacted in producing the judgment. The similarity space resulting from this analysis can be compared to that for the identical stimuli when subjects are asked to filter. Thus, when a pair of dimensions both interact and combine, multidimensional scaling with attention to both dimensions will indicate the nature of the interaction, and scaling with attention to a single dimension will indicate the extent to which the interaction can be disentangled by the per-

ceptual mechanism.

To return to the initial point of this paper, the distinction between the two types of nonseparability, dimensional interaction and dimensional combination, has several implications for the use of multidimensional displays to represent complex information. If, on the one hand, the task of the observer is to detect a particular combination of levels on a number of dimensions independent of the level on any particular dimension, dimensions that interact should be avoided in favor of dimensions that combine. This is because with interacting dimensions the perception of any one dimension is influenced by the level of a second. Thus a given proportion of dimensional values, for example, will appear different depending on the values of the component parts. If the observer is to respond to the proportion regardless of the level of the individual dimensions, interaction can be deadly.

On the other hand, if a single response is to be made to a particular combination of dimensions, dimensions that naturally combine will enable that response to be made as the result of an automatic perceptual analysis instead of a more cognitive condensation of the dimensions. The theoretical basis of this advantage lies in the fact that naturally combining physical dimensions actually comprise a single psychological dimension, to which a single perceptual response can be made.

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Footnote

[1]The authors thank David H. Krantz for his helpful suggestions based on an earlier version of this paper.

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Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

14

REPORT DOCUMENTATION PAGE

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1. ~~REPORT NUMBER~~ 014523-1-T, TR-58
2. GOVT ACCESSION NO.
3. ~~RECIPIENT'S CATALOG NUMBER~~ 9
4. TITLE (and Subtitle)
   6 INTERFERENCE AMONG SOURCES OF INFORMATION IN COMPLEX INTEGRATED DISPLAYS,
5. ~~TYPE OF REPORT & PERIOD COVERED~~ Technical report, 9
6. PERFORMING ORG. REPORT NUMBER Technical Report No. 58
7. AUTHOR(s)
   10 Patricia Somers [redacted] Robert G. Pachella
8. CONTRACT OR GRANT NUMBER(s) N00014- ~~N0014~~-76-C-0648
9. PERFORMING ORGANIZATION NAME AND ADDRESS
   Human Performance Center
   University of Michigan
   330 Packard Road, Ann Arbor, Michigan 48104
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
   11
11. CONTROLLING OFFICE NAME AND ADDRESS
   Engineering Psychology Program
   Office of Naval Research
   800 N. Quincy St., Arlington, Virginia 22217
12. REPORT DATE Feb[redacted] 1977
13. ~~NUMBER OF PAGES~~ 41
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)
   12 47p.
   15
15. SECURITY CLASS. (of this report) Unclassified
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. ~~DISTRIBUTION STATEMENT (of this Report)~~
   N00014-76-C-0648

   DISTRIBUTION STATEMENT A
   Approved for public release;
   Distribution Unlimited
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)
   ~~Qualified requesters may obtain copies of this report from DDC. Others may obtain copies of this report from Office of Technical Services, Department of Commerce.~~
18. SUPPLEMENTARY NOTES
   A short version of this paper was presented to the Midwestern Psychological Association annual meeting in Chicago, Illinois, May, 1977.
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
   perception, integrated displays, multidimensional scaling, filtering
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
   The successful representation of complex information in a multidimensional display depends on the knowledge and exploitation of naturally occurring interdimensional relationships. Sets of dimensions vary in separability, the extent to which the perception of each dimension is independent of co-occurring dimensions. Nonseparability due to integrality among dimensions is distinguished from nonseparability due to masking and distraction. Integrality may result from two separate types of

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

402 524

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dimensional relationships, combination and interaction. Combination can be isolated from interaction using filtering tasks with no speed stress. A method for measuring combination by requiring filtering in a similarity judgment task is developed and a demonstration experiment is presented.